SCIENCE.

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THE DISCUSSION ON STORAGE-BATTERIES BEFORE THE ELECTRICAL CONFERENCE IN PHILADELPHIA.

The sudden outburst of interest in secondary batteries at the time the Faure battery was first introduced in England led to some unfortunate results in the shape of bankrupt electric companies. The first hope was that sufficient electricity to do most of the household work, and give all needed light, would be left at one's door each morning. The idea of 'bottled electricity' was a taking one with the public, especially as it was introduced with the best of indorsements; but the secondary battery has not proved to be such a boon as was expected. In view of this great public interest, the discussion on the subject by many of the leading electricians of England and America at the electrical conference was of especial importance. This discussion shows, as well as any thing can, the present state of opinion among those most capable of judging of the secondary battery. The discussion was opened by Mr. W. H. Preece.

Professor W. H. Preece, London, England. — I have been called upon somewhat unexpectedly to open a discussion on this question of storage-batteries; and I regret very much that I have no notes with me to refer to, and that I shall have to trust a good deal to my memory. As I am not possessed of a poor memory, I don't think I should develop any serious error, although Mr. Edison himself has declared that this question of storage-batteries has developed the most remarkable power of man's latent capacity for lying. [Laughter.]

I very much agree with Mr. Edison's definition, for I think there has been more lying and more swindling and more rascality done over this question of storage-batteries than over any other department of electrical science. Now, storage-batteries have been very improperly called storage-batteries, and I very much prefer to call them secondary batteries. It is quite true that this subject of storage-batteries is one upon which there is a good deal of misconception, which has arisen from the introduction of the word 'storage.' Now, these secondary batteries have been before the world for over twenty years; and all the physicists who go to Paris almost invariably meet with Planté himself, the father of this instrument. For the past twenty years, nearly, it has been one of my great pleasures, when I visited Paris, to pay a visit to Mr. Planté, who has shown me, as he always shows everybody who sees him, the progress that he has made. Mr. Camille Faure, conceived the notion of coating the plates of lead with the oxide of lead. These secondary batteries had not attracted much attention, although Planté's papers deserve the most careful consideration from all electricians; but Mr. Faure found that by coating the positive plate of the secondary cell with a layer of minium, — red oxide of lead, — he considerably hastened the production of the plate. Planté simply depended upon the electrolytic action of the current in peroxidizing his plate. This is an operation that sometimes involves months. Faure's battery fell into the hands of a man who put forward one of the most diabolical schemes that Paris has ever produced. A man by the name of Phillippart placarded all Paris with the most outrageous notices of what this great battery was going to do. Batteries were to be distributed, like milk and ice, at our doors; so that motor power could be obtained and used in our houses, and light could be obtained from them. The result was, that a considerable sensation was created, and an attempt was made to bring out an official swindle; but it did not succeed. Another gentleman was associated with him by the name of Mari. They became associated in London with a gentleman who holds a very high position, and occupies in the financial world a very important place indeed, as the head of the great firm of Mathie, Johnson, & Co., who are large metallurgists. Mr. Sellon joined himself with a Mr. Volckmar. They brought out a compound battery; and a company was formed in London to develop this scheme, and a great deal of money was collected, but all of it has been lost. Mr. Volckmar himself succeeded in playing his part of a plunderer sufficiently to ride about London in a manner indicating a person of great wealth. The fate of this man was sad indeed, for his body was found in the Seine with a bullet through the forehead. Now, two or three other men had been working at this idea, — Mr. Tribe and Professor Bridgeton. They approached the matter in a truly scientific spirit; and the result has been, that Mr. Tribe has brought out a form of secondary cell, although it is not yet in the market, that is a great improvement upon any thing that has ever been brought out before. But all these persons have been working silently upon this subject, and have gone back to Planté's original work, and they have followed Planté's original methods. The batteries that I am going to speak about are hollow,

and the modification of Planté's simple lead cells; the simple cell being two plates placed in a dilute sulphuric acid, one plate oxidized, and the other plate pure. Now, as regards the uses, I have made a great many experiments with these secondary batteries; and first I will speak of the experiments made of their use in telegraphy. Some time ago the idea was mooted that a considerable economy might be effected in the working telegraph if dynamos were used for that purpose. The dynamo-machines are used by the Western union company, and they employ them for their circuits; but they are not used in England, and we have failed to use them for a very obvious reason, which is simply this, that in England we do not work with 'closed circuits.' We work our instruments with rapid reversals; our automatic system, which is so very extensive, sometimes giving us the result of the transmission of three hundred words per minute, with very rapid reversals of very minute currents. It is absolutely essential that these currents should be uniform in their character. Now, the currents produced by the dynamo-machines are not uniform. If a telephone be inserted in a secondary circuit, you will invariably find that you can hear sounds which are indicative of variations of the current, and these variations are fatal to a fast speed of working. But when you use a dynamo, and utilize the current of the dynamo in preparing a secondary battery, you then get a means by which you can produce currents of absolute uniformity. The secondary-battery current flows out absolutely uniform. And, again, it has the great advantage of giving you a battery with a very low resistance. The electromotive force of an ordinary cell is as low as two volts. You may take it as a rule to be two volts. Its internal resistance may be made whatever you like. Now, I had three series of cells made, one set being Dr. Tribe's, and another Planté's: and from each of these sets — there were eight cells to each set — from each of these sets forty circuits were worked; that is, each battery had forty distinct and separate circuits, so that practically we had a hundred and twenty circuits running from these three secondary batteries. Although all worked for about three months, I think the exact time was ninety-six days, all these circuits worked uniformly and perfectly, gave no trouble that would necessitate even the glancing at them during this whole period of three months, and without any attention; when suddenly one failed, and immediately afterward another failed, and then the third failed. They were charged up again, and then they went on for another three months. And they have behaved as well as one could possibly wish; so much so, that one of the first duties that I wish to discharge, on my return to England, will be to arrange for a large supply of these secondary cells, and a further use on a large scale at our battery for the post-office. We have in use, at the general post-office in London, six hundred and fifty circuits centralizing there; and we are now utilizing about twenty-two thousand cells. I think it more than likely we shall be able to work the whole with probably not more than five thousand cells.

Now, as regards electric lighting. I have already used secondary batteries for electric lighting: I have used them in the post-office, and I have used them for my own house. My house is in a portion of the country through which no lines pass for the purpose of electric lighting, and they cannot be found within a reasonable distance: so, if I wanted to light my house by electricity, I must be dependent on my own supply of electricity. I light my house by gas: but I burn my gas in my garden, and I extract from it that which I want, namely, light; and I discharge into the air of my garden that which I do not want, namely, poison. My gas is employed in working a small gas-engine of two-horse power. It is the gas-engine which works a small Gramme dynamo, which, when worked at its full power, gives me forty-two volts and fifty-two ampères. These fifty-two ampères are directed into seventeen cells. The cells are Planté's original cells. The plates themselves are two feet square, and in each cell there are twelve of these little lead plates. The lead plates are made up of four thin sheets of lead, each sheet being about one thirty-second of an inch thick; and they are perforated in squares regularly all over, and these four thin plates are tied together — they are almost woven together — they are tied together with thick worsted. They are arranged in pairs; six on one side forming one pole, and six on the other side forming the other pole. They are placed inside of an ordinary pitch-pine box, and the insulation of the cell is maintained by a thin India-rubber bag which envelops it. It is a loose India-rubber bag of about the same shape, and, when the plates are put in, it forces the India-rubber out, and the bag takes the exact form of the cell, and it makes the cell thoroughly water tight and thoroughly electricity tight. I have seventeen of these cells, all arranged in a series; and my engine, which generates these currents, and charges this battery, is in my garden. My gardener has the gas-engine under his charge. He is an ordinarily intelligent gardener. When he comes on duty in the morning, he lights the gas in the gas-engine, and starts the dynamo which charges my battery; and when he goes away to his dinner, after the engine has been working for three or four hours, the battery is prepared. I go home in the evening: I have got a store of electricity. I have every room in my house fitted up. I have at my bedside a most charming little light, with no smoking, and no trouble with a wick, and no heat, — a mellow light by merely turning on my tap. I have the softest and most delicious light you can conceive of, thrown upon my paper or thrown upon my book. I have had this going on for four months, and I have never had any bother, except on one occasion, when the gardener put his foot on the wrong place, and the engine came down upon his foot, crushing his toes.

I have a strong impression, that, for all isolated places similar to mine, the storage-battery is an essential thing, and I think that some one is bound to work out this question. Several are now pegging away at it. Sir William Thomson spent much time in investigating this subject, and has given it a great deal of attention, but has not succeeded, simply because you can use a Planté cell untrammelled by any patent. It

is at your disposal, and nobody will interfere with you. If anybody else chooses to follow my example, I think they can do precisely the same thing. But there are, after all, one or two other uses for secondary batteries. Now, I have been very luxurious and very extravagant in carrying out this arrangement. For instance: I have a little daughter who has a very pretty doll-house. Her doll-house consists of six rooms; and each room is well furnished, and well populated with charming little dolls. It is, of course, necessary that each room should be supplied with a charming little electric light: so each room is supplied with this light. Then, I have a cigarette-lighter, consisting of a piece of platinum which can be rendered red-hot by the secondary battery. The difficulty in doing that sort of thing with the usual mode of distribution is that you want the benefit of cutting off a portion of your current. I interrupt a current, flowing, say, six-tenths of an ampère, by putting into the circuit, by a switch, a secondary cell, that diminishes the light, and sets up a counter-electromotive force of two volts for the time being. While that cell is in the circuit, your light is a little dim; but when I take from the poles of that secondary circuit two wires in connection with a piece of platinum wire, then the current passes through the platinum; and this current is due to the two volts from the secondary cell. This piece of platinum wire is heated up with a current quite sufficient for the purpose, with only two volts.

Now, there is another field in which satisfactory experiments have been made with secondary cells, and that is, in lighting up trains of cars by electricity. This has been done on one of our railways between London and Brighton. The railway company has been for some months past lighting up one of its express trains with secondary batteries. The dynamo is worked by the motion of the wheel, and the dynamo charges the battery during the time that the train is working, and the battery is being charged during the whole of that time, and the current is being extracted from the battery; so that you have a light in your carriages which is perfectly steady, and quite independent of the motion of the train. And that leads me to a point which I omitted, and which led me to work so hard at secondary batteries; and that is, that a secondary battery renders the current produced by the inconstant engine and the inconstant dynamo perfectly steady.

It is a difficult thing to say, that, in making an appliance of any kind, we have reached absolute perfection; but I can say this, that, when you have a secondary battery inserted in the electric-light circuit as a shunt (p. 388), it renders your current perfectly uniform, and your light is as near perfection as it can be. Supposing that your lamp requires fifty volts, then you will require twenty-five cells; and I should think myself that it would be quite possible to make cells for this purpose that ought not to cost more than five shillings a cell. You put twenty-five of these in cells: the first current that goes through, simply charges the lead plates; one is coated with oxide, and the other is clear; and you get a counter-electromotive force of fifty volts. The consequence is, no current whatever passes through the secondary cell unless it has once been raised to fifty volts. The whole current goes through your lamp unless there is flickering of the engine. Then, if there is flickering of the engine, the energy that is stored up in the battery passing through the lamps makes the light uniform, and in that way you get the storage effect by the use of the secondary battery.

There are certain defects that have developed themselves in these batteries, that have been gradually cured. The great defect in all secondary batteries is due to buckling, — a fact due to the formation of peroxide upon the plate. You will find your lead plate will buckle up into all kinds of positions, and the two plates will come into contact. This difficulty I have sought to overcome by supporting the two plates by means of a plate made of paraffine-wood; but the most effective arrangement that I have tried is ebonite. This ebonite is furnished, stamped out to the proper size, and is very light and very thin, though quite equal to preventing all buckling.

Secondary cells have not been in use long enough to enable us to determine how long they will last. I have had them in use for four months, with a sign of but little disintegration of the positive plate. I think that the plates will have to be renewed only about once in every two years. Those that I have in use were re-charged at the end of four months.

The charm of the whole thing is such, and its cost is so trifling, that I shall keep it in my house; and I am quite sure that all those who have worked in the same direction in regard to this matter of electric lighting will never give it up. The electric light itself has some sort of a charm about it. Objection is made to the cost of introducing it; but I have protested often and often against the comparison that is drawn between the cost of gas and the cost of electricity. The two things are not to be compared. When we indulge in luxuries, we don't compare the cost of the luxuries with other things. If you want fine 1834 port, you don't compare its price with that of ordinary claret. If you want to indulge in a fine pheasant, you don't compare it with the old cock that crowed before Peter. So, when you have a delightful luxury like electricity, you don't want to compare its cost with that of gas or sperm-candles, or any other mode by which life is shortened and ultimately destroyed. Here we have something that in the out-of-the-way houses tends to lengthen life and to satisfy us, giving us something cool and delicious; and I say, all comparisons with gas are utterly ridiculous. In reference to these enterprising light-companies, they will soon bring electricity to our doors; and we will all take it. When people can get electricity at their doors, and can get it without much cost, as indeed they can, they will certainly have it. So I look upon the days of gas as being numbered; but gas is a most important power, and its uses are just in their infancy. The days of gas as a distributer of power and heat are coming. At the same time, electricity is going to supply light such as we want.

There are many facts connected with the working that I should have liked to give you. I should have liked to give you the efficiency. I have made careful experiments as to the efficiency of the storage up to the present time. The cost is certainly within the reach of every man in this room. Every single man in this room can afford the comfort which this light will give him; and an electric plant will enable him to live four or five years longer in this world than he would without the electric light.

Prof. W. H. HARKNESS. — I was very much pleased and gratified at hearing Mr. Preece's remark as to the use of secondary batteries. After all that has been said on both sides, it is gratifying to find that we have a certain and valuable method of lighting which is effective and economical. I wish also to add my testimony on one or two points which Mr. Preece has mentioned, and that is, to the courtesy uniformly shown by Mr. Planté to any one who visits him at his laboratory. I had the pleasure, with some friends, of visiting his laboratory, witnessing many experiments made with a large number of secondary-battery cells. As we all very well know, his invention has resulted in the adoption, not only of those secondary cells, but also of the cells themselves. The use to which he has put them, however, has led to many absolutely new experiments, so far as I know. It is also a point of interest to know, as probably some of you do know, that Planté himself tried a method, many years ago, of covering the plates with minium. If Professor Barker were here, he would bear witness to the fact that Planté has used both; that he tried the same thing several years ago, and found that it was not so effective as a battery of his own plates by the method adopted, which, though necessarily slow, probably resulted in a better form of cell. So it is gratifying to know, from the experiments of Professor Preece, that we are advancing, so far as new experiments are concerned, and that we are finally going back to the original form devised by Planté.

There may be one reason worth mentioning. We are all well aware of the careful and interesting experiments referred to by Mr. Bright, on the chemistry of the secondary battery. These experiments show us that there is a greater or less formation of the lead sulphate in connection with the cell adopted; and that also shows us why the electromotive force, having run down, after a period of rest, is recovered to a certain extent. A great many points have been cleared up that were certainly quite enigmatical before. Now, some experiments, and I think some of those that have been published by Professor Barker, go to show, that, in the Planté cell as formed by Planté, — by a rather slow and tedious process, but by the method of Planté, — there is at least a small amount of lead sulphate produced. I take it that the giving-out of the cell is due to the formation of sulphate; so that, if these cells are formed by the rules laid down by Planté, they will have a tolerably long life. Now, just one word with regard to the cost. You will remember that a year or so ago Professor Langley showed, I think beyond any question, that the percentage of the radiant energy from an Argand gas-burner that is effective in producing illumination is less than one per cent. It certainly is a very curious result. It is less than one per cent, and there is little doubt about the energy which goes up through the chimney.

Mr. N. S. KEITH. — Planté was evidently far ahead of his time. He produced what is to-day found to be of vast practical importance. In 1860 or 1861, about the time of his published experiments, there was no electric lighting; certainly none as it exists to-day. There were then electric-lighting men who were far ahead of their time; but it is only within the past four years, we may say, that we have had any possible application of the secondary battery. I am led very forcibly to consider this point, because in 1878, during the experiment I was then carrying on in the electrolysis of lead, and in collateral experiments which relate to the chemical action of lead in various solvents and in various electrolyses, I was led to make a secondary battery after having made one of Planté's. I made one by coating the plates with peroxide of lead by electro-deposition — not peroxide of lead formed from the substance of the plate itself, as by Planté; not by coating the lead plate with oxide of lead, or peroxide of lead, as the case may be, from external sources; but by coating it by deposition from a solution of lead in which the plates were immersed. I took two hundred and forty cast pieces of lead plate, each one foot square. I divided them into ten cells, making twenty-four plates of each cell, twelve of which were positive, and twelve negative. By using a suitable solution of lead (a sub-acetate of lead in nitrate of sodium), and by treating that with a current of electricity, I produced decomposition of the solution, deposition of peroxide on the positive plate, and at the same time metallic lead was deposited upon the negative plate in a very finely divided and crystalline state. Some hydrogen is also deposited with the lead, — an equivalent to the oxygen that is deposited in chemical combination with the lead upon the positive plate. These plates, after pressing the metallic lead so as to cause it to cohere and adhere to the plate, were taken from this solution and immersed in sulphuric acid, and gave a very satisfactory secondary battery indeed. At that time (in May, 1878) I ran a dynamo as an electric motor with this battery, and I effected some chemical and electrolytic decompositions in a solution of sulphate of copper, and did some other things which were then the only possible commercial applications of secondary batteries. Since that time, electric lighting by incandescence has come to the front, and we find the great use of secondary batteries which has been so forcibly set forth by Professor Preece. At that time we did not have telegraphy by the dynamo; but we had telegraphy by the use of the primary batteries with which we are all so familiar. I have since that time carried on a considerable number of experiments relating to secondary batteries. The whole subject is an electrochemical one. There is a chemical decomposition of the solution by the passage of a current of electricity. There is a decomposition of the water of the electrolyte either primarily or secondarily. Oxygen goes

to one plate, hydrogen to the other. For a new experiment I have taken solutions which suffer decomposition without delivering free hydrogen and oxygen. I have taken, for instance, solutions of the sub-salts of lead. A current causes decomposition, and a deposition upon one plate of peroxide of lead, and, upon the other, of metallic lead. For instance: I have taken, for one plate, a plate of carbon, and, for the other, a plate of lead. A solution of a low sub-salt of lead was used as an electrolyte. By passing a current of electricity through it, the action is to raise the sub-salt to a proto-salt. This takes energy, which is absorbed by the chemical action. Then the charge of electricity is returned until the peroxide of lead has again entered the solutions, and the lead has also entered into the solution. The action of the charging current of electricity is to raise the electrolyte to an acid condition; but the charging action is stopped before that point is reached, because the end would be defeated in passing it. I am also carrying on some experiments in the way of storage for electricity or in the use of secondary batteries. I can hardly give particulars, except this: the idea is to preserve the integrity of the plate — of the inside plate — for an indefinite length of time, say, as long as may be practically worth while. So far, after some months' use, I have been able to oxidize the plate to the desired depth (say, one-sixteenth of an inch), and preserve a backing of metallic lead. Under this change, if my theory and practice be correct, I will not be obliged to replace, as in the present known storage-batteries, the oxide plate.

Prof. CHARLES H. KOYLE. — I should like to say something in reference to the theory of the secondary battery. There are no substances which, placed in juxtaposition in a secondary battery, will give the electromotive force that the peroxide of lead, and the lead of the Planté cell, laid opposite to each other, will. It remains as it was in 1859, when Planté experimented and wrote. I have experimented upon other substances; and, although my experience has not been exactly useless, it has been the next thing to it.

The necessities of the plate, then, are the only difficulties to be considered. They are three, and they are very simple ones. First, the plate made must be a conductor of electricity, and that leaves us the metals. The plate, in the second place, must resist the ordinary action of sulphuric acid: that leaves us lead and four or five expensive metals, — platinum, and so on, and gold and carbon. Our list is very much reduced, as we have practically, for this purpose, only carbon, as the expense of the other metals is too great to allow them to be used extensively for commercial purposes.

Now, when we get the third and last condition, — and that is, that the plate must resist both electrolytic action and the oxidizing action of the current, — lead will resist the electrolytic action of the current moderately well. But the oxidizing action of the plate reduces the lead to a peroxide in a very short time. That leaves us only one thing for a secondary battery of the future, — carbon.

I think there is no way of upsetting that very short argument. I should be very glad to know if there is. Now, then, the manufacturer of the carbon plates called good, makes plates which shall contain a very large amount of the substance, because the capacity of the storage-battery depends entirely upon the amount of lead and peroxide of lead which you can put upon these plates. They are the substances that you will have to depend upon for your electricity. Of course it is not necessary to say that they will answer the purpose: they are the substances in which the chemical action takes place.

Now, it is possible to take carbon and to manufacture carbon plates by the ordinary method. Take ground charcoal, ground gas-carbon, ground flint, and mix gas-tar with it, or molasses, or any hydrocarbon. This is put into a press and the shape is given to it; and then it is put into a closed furnace and carbonized, so as to drive off the gas, and leave the carbon free. Those plates are pretty good for ordinary primary batteries; but when your lead contains a lot of little holes, very much as the lead now in use does, the plate is very apt to disintegrate. There is such an enormous amount of surface exposed, that the action of the cell is apt to disintegrate the plate, and the metal will scale off. A better way to make the plate is then to be considered. There is a method of making these plates which is very much liked, — a method in use by the U. S. lighting company in the manufacture of carbon for their incandescent lamps; that is, to take celluloid and put it through some chemical operation which deprives it of a part of its gum, thereby leaving a substance very easily carbonized. That substance may be cut into any shape of plates desired. You can make some of these plates thick, and some thin, and you will always have a good plate. It is not very strong, but it is a good plate. Another method, which I myself have used, I have found to work very well, and I shall have more to say about it in the course of a few minutes. At present I can only tell you the general method. I take gas-tar and put it in a closed furnace, and drive out the gas, and so get rid of the ordinary illuminating-gas, the heavier gas, which is condensed as it passes through the tubes. The constitution of the coal-tar depends, first, upon the constitution of the coal; in the second place, upon the temperature at which the gas is driven out. The object is to get out the lighter parts of the coal-tar. Coal-tar is a very composite substance. The physical qualities of coal-tar vary very much, according to the temperature at which the gases were originally driven out, and, again, according to the temperature at which evaporation is carried on. It requires months of experiments, as I have already said, before one can determine what is needed. This coal-tar, when it is thus taken and evaporated, and brought down to a requisite consistency, which is a matter of experience, is taken and put into a box prepared for the purpose, and put in an oven which is closed. The tops of these vessels are covered with sand, and one thing and another, in the ordinary way, to prevent the presence of air; then the heat is

turned on; and gradually this stuff begins to boil. You cannot take up this evaporated mass and tell what will be its quality, until it has been evaporated. Then, formulating these three things, you can tell what temperature you want to use under this tar in a boiling state. Then I have devised a process of quite suddenly increasing the heat. This is done by means of a double oven, one part being heated moderately, and the other to quite a high degree of heat. When the tar no longer boils, it is suddenly carbonized. You then have to make your plate. I take this substance and cut it. It is true, it is carbon, and it is pretty hard, and there is difficulty in cutting it: so I have devised another method to free myself of the trouble of cutting the plates, and that is, to prepare the plates of a proper size. This is a process which I developed last winter. The method of manufacturing which I have described is susceptible of considerable uniformity. The character of these plates is porous, and they are of considerable value in a secondary battery.

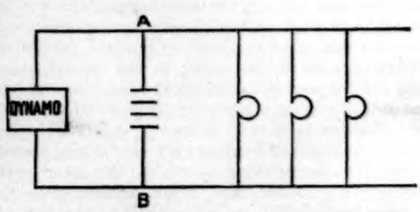
Planté, of course, is the great originator of secondary batteries of modern times. You can take a Planté cell, and you can get forty per cent from it if it is properly charged. A fair battery will return proper work up to ninety per cent. It does not always do it. It has to be carefully charged, and it will return, under careful circumstances, ninety per cent.

Mr. Frank J. Sprague. — Ninety per cent of the form: is that what the speaker has told us? I should like to know what part of the circuit he uses. Does it include the battery?

Mr. Koyle. — Including the battery, of course.

Professor Forbes. — I merely wish to draw attention to this very point. The difficulty about manufacturing those plates is to get them of a proper length. We should know exactly what we are dealing with. The action is exactly, of course, as it has been described.

I want to show to you how the equations come out, because they are very interesting in showing the regularity of the secondary battery upon the brightness of the lamps.



Let E_1 be the electromotive force of the dynamo, R_1 the resistance of it; E_2 the electromotive force of the secondary battery, R_2 its resistance: R_3 we will call the resistance of the electric lamps in the circuit. That will represent the resistance of the lights which come into play. This is given by a well-known law. Perhaps that is the simplest way to take it. Let us call the potential at the point A, e_1, and that at the point B, e_2. These are the two points where all the three circuits unite, and e_1 and e_2 are the potentials at those points. Suppose that e_1 is greater than e_2, then the current circulating in each of these three circuits can be put down immediately in terms of the quantities which are there shown, involving the two unknown quantities e_1, e_2; the current which is circulating in the partial circuit of the dynamo always taking the direction of the current as positive when the current flows from e_1 to e_2. The current in this part of the circuit will be $\frac{e_1 - e_2 - E}{R_1} = C_1$, R_1 being the resistance of this circuit. C_2 is obtained from C_1 by replacing E_1 and R_1 by E_2 and R_2 respectively, and similarly for C_3 (R_3 being the resistance of the lamp-circuit). Finally, we have the equation that the sum of all these equals zero; that is to say, the total current which passes through any one point is equal to zero, which is a well-known law. We have, therefore, the sum of these currents $(C_1 + C_2 + C_3)$ equal to zero.

Now, this $(e_1 - e_2)$ is in reality the unknown quantity. It is a difference of potentials. It is the single unknown quantity of this equation. The result which we arrive at on working out this equation is, that $e_1 - e_2 = \frac{E_1 R_2 + E_2 R_1}{R_1 + R_2}$. This is a very useful formula, and probably is well known, and has important applications here. The application especially is to finding the current which flows through the lamp-circuit. The current C_3, which is the current flowing through the lamps, is equal to $\frac{E_1 R_2 + E_2 R_1}{R_3(R_1 + R_2)}$, that is, the final value of the current which is passing through the resistance of the lamp-circuit.

Now, here is a remarkable thing, — that, however much the irregularity of the dynamo-machine may be, the current is found to be very steady in the lamp-circuit when we use the secondary battery in that position. The reason of that is, the secondary batteries which we are in the habit of using have an extremely small resistance; and, whenever we use secondary batteries, you will understand that we use an infinitesimally small resistance, compared with the resistance of the battery or the resistance of any such lamp-circuit.

If, then, we take the resistance of the secondary battery to be zero, our equation simply gives us, $C_3 = \frac{E_2}{R_3}$, with the other quantities cut out; that is to say, the current is exactly the same as if this dynamo was not working at all, and as if we had a battery of infinitesimal resistance, with this electromotive force of E_2 working through these series of lamp-circuits.

As I am here, I may as well make a few remarks upon another point in connection with these secondary batteries. Of course, the great difficulty we have had in the past times was, in the first place, that we used thin plates, and they buckled. This has been the most serious objection that we have had. And it is very satisfactory to hear from Mr. Preece that he found that he practically gets over the buckling of the Faure cell and Volckmar battery. The

force generated in these plates, tending to buckling, is something enormous.

I do not think any ordinary separator of material which he speaks of would be sufficient to prevent the buckling of a Volckmar accumulator; for the force generated in these plates, tending to buckle them, is something enormous, and no ordinary separator would be able to resist this. If such resistance were offered to them, I think they would break. The reason why he has succeeded in getting rid of this buckling is because he has reverted to what is evidently the most scientific, and which will ultimately be found to be the most probable, form, that of the old voltaic battery. The objection to the Faure cell was the want of perfect symmetry in the plates, tending to make them buckle, and want of homogeneity in the surface, which tended to introduce local action. And that is the one great defect which has been pointed out some time ago, which I think most people recognize now in all these Faure cells and Volckmar batteries.

I wish Mr. Preece would give us some further information about the length of life of these cells; because although he has them in his charming house, and although they last only four months, does not everybody who will call want to obtain some more definite information? and I think there must be some gentleman here who can give us more information about the life of these batteries. As a matter of fact, the larger form of Planté battery, the improved type of batteries, which I believe were tried generally with nitric acid in order to render them more powerful, have been generally used with lead, but only within the last year or two, and therefore their absolute life is not determined; but I believe it is perfectly conceded that these voltaic batteries as they have been prepared with lead, and as Mr. Preece has them in his own establishment in his own private house, are the longest-lived batteries, — far longer lived than any artificial batteries such as the Faure cell and the Volckmar.

Mr. F. C. Van Dyck. — I do hope the people will not be discouraged in working in the line of other batteries besides the old one. I think there are cases in which the battery is sure to have a long life, and sure to keep itself charged without loss for a great length of time.

There are many uses for such a battery as that; and my own work satisfies me that the zinc alkaline and copper battery will fill a considerable want; for instance, running the magnetic apparatus in observatories, and work of that kind. I have made a small battery of that kind, using a spiral of copper above, and amalgamated zinc below, so as to avoid the falling-down of the deposit of zinc upon the copper, thereby amalgamating the copper, and rendering it far less efficient. Although the electromotive force is only ninety-seven and ninety-eight hundredths of a volt, still we found by actual trial that charging the battery and letting it stand, then letting it run down and taking the readings at the time, and then letting it stand for two or three months — we found there was not enough difference in the readings to show the slightest loss; the battery had retained its charge, so far as we could find out by the means at our command, perfectly for two months; which I think is a good showing. Long ago I found, in using a battery, that I had to be very particular about the electromotive force to be used in charging it. I have not finished my experiments so as to state precisely the electromotive force, but it is somewhere between a Daniell and a Grove. If you charge a cell of that kind with a Grove cell, you will find that the copper strip will be altogether dissolved by alkaline solution, forming the cuprate of soda or potash, according to the alkaline used. Then that breaks up in the form of oxide of copper. But, if you are particular about not running beyond the Daniell, there is no such difficulty experienced.

I want to say a word on the carbon question. I am interested to know whether anybody has succeeded in producing oxygen on carbon to any considerable extent without disintegrating it. I have had great difficulty, in my experiments with the secondary battery, in getting oxygen on my carbon plate, and depositing the oxide of lead. I have found, if I succeed in bringing forward the oxygen in the slightest degree, it leads to the disintegration of the carbon by means of the oxygen. Hydrogen does not do it at all. Now, if we place a carbon disk with a platinum disk in an ordinary Volckmar battery, we will soon discover how long that carbon will last. The oxygen seems to have the power of forming an accumulation in the pores, and crowding out the carbon, more than the hydrogen does. I dislike to have any thing to do with the lead-battery mentioned. I think that this matter of the copper-battery is worthy of passing mention, because I can see those cases arise in which we should like to have a battery that we could charge, and know we could depend upon, and that would not lose its charge even after two months. I am positive that anybody who tried it would be pleased with the properties of the copper-battery made in the usual way, with amalgamated zinc alkali, either soda or potash. Preference should be given to soda on account of its being so much cheaper. The method should be to use the Planté battery with chlorate of sodium in it. I think the tendency of the copper to dissolve, and to break up into cuprate forms, is not any greater when the soda is used.

Mr. Koyle. — I just wish to inquire of Professor Van Dyck how his carbon is made: it makes considerable difference. I should like to know the manner in which the carbon plates are formed. If they are formed by the ordinary method for use in the primary batteries, the carbon being made out of coal-tar carbonized, they are very brittle, and disintegrate in the battery; but if formed in the manner I speak of, from coal-tar, pure and simple, so that they seem to form a very much more homogeneous mass, there is not only a striking, but a permanent difference of the plates.

Professor Van Dyck. — I will state that I use the commercial carbon simply.

Mr. Koyle. — Another word. I think that there is a great deal of difference between the secondary

battery composed of carbon plates and one composed of lead plates. I do not see myself the reason for an expression of the opinion that the Planté battery is decidedly more scientific than any other batteries composed of a plate of polarizing substance distinct from a plate of lead. It is easy to construct a Faure battery that will last forever, if you only make the plates large enough. Lead has some weight, as is well known; and, when you are going to make a Planté battery of sufficient size to last any length of time, you will have to make a secondary battery of enormous weight. For any other purpose than putting it down in the cellar to stay, the weight is a great factor. I think that a lead plate a foot square, the ordinary size, will weigh something in the vicinity of six pounds, — I do not guarantee that exactly, but I believe it is in the neighborhood of six pounds, — and a square of carbon plate of the same size weighs about three-fourths of a pound. Now, a battery made of eleven plates of lead of this size gives you something like sixty or seventy pounds. If you want to use electromotive force, as in some cases you do, of a hundred volts, you have a great weight: it would be fifty of those cells, of sixty pounds each, which would give you about three thousand pounds; and that is altogether apart from the weight of the electrolyte and the box. Carbon plates will make a difference of about twenty per cent, and the carbon plate has the advantage of always remaining intact. It will not disintegrate, and will remain permanent as long as the box will, or any thing else about it.

Mr. Elihu Thompson. — I should like to have a method which will tell whether the plates will disintegrate or not. Consider the plates that received the deposition of peroxide of lead. Suppose we were to select one particle of oxide which has been formed from the surface of the lead: what will be the electro-chemical conditions of that particle? Evidently the peroxide itself is in an electro-negative condition, far more so than the lead plate: consequently it will set up an open circuit, and distribute its oxygen more or less to the surrounding lead, and thereby eat into the lead deeper and deeper, destroying the life of the battery in time. It would seem, from this consideration alone, that the lead-battery is certainly limited in its life.

Let us take the case of the carbon plates. Has it yet been proved that carbon is stable in the presence of peroxide of lead, in contact? Perhaps this may disintegrate the carbon, and oxidize it into oxide of carbon, and at the same time reduce the peroxide of lead to the teroxide of lead (PbO_3).

We have here two different substances, one highly electro-negative; and the carbon, perhaps, may be inert, and then it may be different in electromotive force ever so slightly, and we will have a local circuit which will take oxygen from the peroxide of lead, and oxidize the carbon. If we wish to make a test of that, let us take a massive piece of peroxide of lead and a specimen of the carbon which is to be tested, and place them in an electrolytic liquid (for instance, dilute sulphuric acid), and see whether we have a difference of electromotive force between those two substances, putting in the circuit some means of testing a feeble current. If there is no such difference, the stability of carbon in contact with the peroxide of lead would be established. It may be, also, that the states in which carbon is known to exist may control the matter to some degree. It is well known, that if we take a stick of carbon, and put a current through it of a sufficient degree to almost vaporize the carbon, it undergoes a certain change of condition into the graphitic variety, and, in fact, it takes a plastic form, as I have often observed. You can take this carbon and use it, or any portion of it, to write with as you would write with a lead-pencil: whether it would be suitable in that form is another question.

Professor James Dewar. — There is one point I have noticed that is of practical use in reference to secondary batteries, and that is as to the inequalities in the various styles of batteries. I have had an experience of six months with one form of storage-battery, — the commercial battery as it is now in use on a lamp-circuit. As it is arranged, it is used for lighting forty incandescent lamps. We have only ten or twelve of these lamps in use at any one time: consequently the demand on the battery is not very great; and hence, in charging the battery, we find with a twenty-ampère current, which is the current used in charging them, that instead of having to charge the battery all day, as I believe would have to be done in case the whole forty lamps were to be used, we charge for two hours in the morning, or until the cells give off gas from the plates, when we consider the charging as completed. I believe, after three weeks' use of this battery, that some four or five of the cells that were to serve in the first place became feebler than usual; that is, the lamps were not up to their usual standard of power. The next morning it was found that certain of these cells, four or five of the twenty-one that formed the battery, were much lower in their electromotive force than the other cells of the battery; that is to say, if the mean of the electromotive force was 1.85 volts, they were down to less than one volt. It was thought, in the first place, these cells might, perhaps, become exhausted by short circuits; but, from very close examination, there were revealed no short circuits in the cells; and, furthermore, when the charging current was put on again, those cells were the first of the whole battery to give evidence of being charged. In other words, it would seem as if the storage capacity, if I may use that expression with regard to those cells — the storage capacity of these particular cells had been diminished in some simple way.

Now, we restored those cells by a process, — the process which we were instructed to use in the first place. A battery was first set up; that is to say, a prolonged charging of the whole body, — a charging of some twenty hours with a current of twenty ampères, and then a discharging of the whole battery on a fixed resistance, which was about equal to the ultimate resistance (say, eight-tenths of an ohm); then a charge of twenty hours with a twenty-ampère cur-

rent, and again a discharging the battery for three or four hours on this fixed resistance; then a re-charging for twenty hours; and at the end of that time the battery was in good condition again, and those particular cells which we had found had given out before did not give out again for several days; but in every case, I think, where that process has been repeated three or four times, it finally took about three weeks for these batteries to give out. I don't remember exactly now whether the same cells are involved, but I think that out of the five or six cells, four were involved every time. We occasionally find another cell going in the same way, and I think it is a question of time when all the cells will probably behave in the same way: otherwise the cells which are good, and which have not given any trouble, are good cells; and there is no doubt about the resistance of the whole battery. The electromotive force is very constant, with the exception which I mentioned, and the light is very satisfactory. But I am not at all sure that Mr. Preece has found a solution of the light in question by means of the secondary battery. It is to be hoped that he has. My experience rather indicates that we have not got a storage-battery, or a secondary battery, which will be a practical instrument.

Mr. PREECE. — I should like to reply to some of the observations that have been made; and, in the first place, I should like to corroborate what has been said about the percentage that the storage-battery would utilize in shape of light.

Very recently Professor Dewar was kind enough to make a calculation for me that brought out a very interesting result, and the result was this. I wanted to know the relative proportion of energy expended in different modes of artificial illumination. I wanted to know how much was expended in the sperm-candle to give one-candle light, and how much in a gas-flame, and how much in electric lamps. The result of Professor Dewar's calculation was to show that in a sperm-candle for one-candle light we expend ninety-seven watts. The experiment with gas showed, that, for every candle given out, sixty-two watts were consumed. Now, I have been experimenting with various incandescent lamps; and one lamp gave a result showing that it was possible to obtain one candle for two watts and half. Still with arc-illumination — use of arc-lights, such as are used in the street — we get a candle for each watt expended; and in the arc-lamp, when bereft of the hideous structure put around them to destroy or reduce their light, and we get all the light emitted, we shall probably get a candle for each half-watt. If we can get one candle for the expenditure of one watt, and we do expend ninety-seven watts in the process, it is clear that ninety-six watts must have been wasted, as it were, in that effect.

There is another point that arises out of this, to which I want particularly to call your attention; although I am afraid I am going to get into a subject in which, if introduced, many of you may set me down as very heterodox. My doctrine is simply this, — that I believe the days of the arc-light are numbered, and that all the lights in the future will be furnished by the incandescent lights. My reason for saying that is simply this, — that, up to the present time, in the incandescent lamp such as we have, the light is produced by the expenditure of from four to five watts per candle. Improvements, and very rapid improvements, are being made in the form of the carbon filaments. We are now using lamps in England that give us light with an expenditure of only two watts and a half per candle. If improvement goes on at this rate, I am quite certain that before another decade we shall have incandescent light that will give us one candle for each watt. When that is the case, then the incandescent lamp will be used in place of the arc. The arc requires constant personal supervision. It requires mechanism to keep it in order. It only lasts a short time, whereas the incandescent requires no attention whatever after it is put up; and its life is very considerable indeed. In London, lamps can now be obtained whose life is guaranteed to be a thousand hours. I believe on this side of the water they are guaranteed to a certain extent, I do not know what; but if we can get incandescent lamps giving a light at the expenditure of a watt per candle, and whose life will be over a hundred hours, then it will be a case of good-by to the arc-lamps.

There was one other point that I did not mention in regard to my battery; and that was, I am using only seventeen cells. I am using only thirty volt lamps, and I use them for security, first, because it gives me very few cells to keep in order; and, secondly, because the electromotive force is so low that there is not the slightest fear of shock, and consequently there is not the least fear of fire due to a short circuit or imperfect action in any of the insulation. In isolated houses, the lower you can reduce the electromotive force, the safer it will be.

Now, with regard to carbon: I am sorry to say that I differ altogether from the view that has been expressed, that carbon is likely to replace lead for secondary batteries. Carbons do disintegrate with us in London to a very large extent in the present form of battery. I had the bi-chromate battery: the battery we principally use is a bi-chromate battery. In that battery the carbons do not last more than twelve months. They do disintegrate: they tumble to pieces, they become quite soft and spongy; and it is quite impossible to use any form of carbon, — moulded carbon; and we are obliged to use cut carbons, as the moulded carbons would not last more than two or three months. While the cut carbon does not last more than twelve months, the lead in the secondary batteries would last more than twelve months. I said that I did not agree with the remark that was made, the statement that it lasted only four months: I think it will last more than twelve months. I know of houses where they have been in use for more than twelve months, and I am quite satisfied that the lead used in the one I have described will have a durability of more than twelve months. I shall not be the least surprised if it lasts for two or three years.

Now, I look upon the employment of the secondary battery for starting the gas-engine as simply

barbarous. I say this because I believe that the whole — I should not say the whole, but the greater portion — of the causes that have brought the secondary batteries into such ill repute are due to the various barbarous practices that have been adopted by those who have been using secondary batteries. And these practices have been indulged in without the person knowing the injury they were doing to the battery. The practice has been to dash in a piece of metal in order to see the sparks, and then to say what splendid order the battery was in. A more iniquitous or sinful practice could not be adopted. It is just like a doctor cutting off a man's forehead to examine his tongue. Such a practice as that has given the poor battery a straight blow between the eyes, which it will struggle with for days. Any practice that constantly calls into action the force of the battery on such a short circuit is simply barbarous, and tends to destroy the battery more than any thing else. I test every cell of my battery every morning with a galvanometer of a hundred ohms resistance. The galvanometer is simply run through on the cells: it takes but a short time, and you can see exactly the condition of the cells without in any way interfering with the condition of your battery.

There is one point about which I should like to have Professor Dewar tell us a little something. There is one defect, and it is a very peculiar defect, in all of these forms of secondary batteries. It follows, after a short time, from covering the plate with minium, and it is the formation of trees on the plates. That formation is observable in that form and type of battery, and it is not being observed with the Planté. Planté himself has never suffered from the formation of trees; nor have I, in the batteries I am using, seen the slightest sign of these trees: therefore I think that the mode of separating, to prevent buckling, in my case will be a cure. It will not prevent treeing; and therefore it will not cure that defect, which is one of the most serious defects of the Faure battery.

Now, I will not say any thing about primary batteries. I mentioned, when first speaking, that there had been a good deal of interest expressed about secondary batteries and their introduction; but there has been none expressed about primary batteries. Such a battery as we have to-day has been brought before the London public; and it has been shown that the products of the battery formed in its action will repay the cost of the battery, and that the products can be sold for more than they cost: therefore it has been suggested, that, if it be true, it would be a splendid thing for the government to buy up all these batteries, and to use them, and in that way to pay off the national debt. A great many experiments have been made; and the results of these experiments are not to be discarded. They are successfully used for certain purposes, but they are not just yet going to knock out of the field secondary batteries in the way that has been described before us.

The qualities to which Professor Dewar referred are due to the impurities of the lamp. I have suffered somewhat in the same way. I have cured it precisely in the same way by putting on the power for twenty hours; and in that way the impurities, or whatever they may be, have been jostled out. The result has been, that this has had to be done about every two months, whenever there was a repetition of the difficulty. What I am going to do is this: I am going to have my battery in such order that I shall devote one day to the charging of the battery; and my gas-engine will be going all day long, and that will charge up my battery; and I shall have on that day sufficient storage-power to enable me to keep my house lighted for the rest of the week.

Professor JAMES DEWAR. — My views with respect to the chemistry of secondary batteries may be shortly expressed as follows: I feel that, in the future, some other body than the peroxide of lead will be discovered, which will more efficiently represent the amount of energy absorbed. I take it to be, that, after all, it is the question of the relative efficiency of such batteries which is the real question under discussion. The electrolytic action is, after all, the question we are to discuss. Now, it seems to me, apart altogether from the difficulties of local action, the question is whether any other chemical bodies likely to be formed during electrolysis will be as efficient as the peroxide of lead in the construction of secondary batteries. Let us take the case, then, of the type of these reactions. In ordinary cases of chemical action, we have often two actions taking place. Take, as an illustration, the formation of chlorate of potash. As a matter of fact, in this case an exothermic and an endothermic action take place side by side. The total action takes place, like the majority of chemical actions, with a considerable evolution of heat; but the evolution of heat is, in this case, due to the formation of the chloride of potassium, and not to the formation of the chlorate. A chlorate would be endothermic, would be minus, or there would be a reduction of the temperature during the production of such bodies: therefore the energy for the formation of the chlorate is really in some miraculous way extracted out of the energy produced by the direct formation of the chloride of potassium. The production of peroxide of hydrogen during electrolysis resembles that of the chlorate of potassium. It is endothermic, formed with a considerable absorption of energy, and consequently can decompose into water and oxygen again with an evolution of heat. If we could construct a battery in which all the oxygen is fixed in this way in an unstable body, there is no question but we could produce by this means a much higher electromotive force in secondary batteries. If we take the case of electrolysis of salts, we know very well, that, in a great majority of salts used for ordinary purposes, the electromotive force is practically constant, while that accords with the well-known fact, that the thermal value of the formation of the majority of soluble salts is nearly independent of both the acid and the base; that is to say, it is nearly constant, giving something like fifteen thousand gramme units per equivalent. For a direct battery, therefore, comprised of soluble oxide and soluble acid, the electromotive force is practically

constant. To get a higher electromotive force, we must produce bodies like permanganic, chloric, or chromic acids, or peroxide of lead. It would seem, during the electrolysis of water, peroxide of hydrogen is produced in very small quantity. The peroxide-of-hydrogen reactions, which are so easily recognized in an acid fluid which undergoes electrolysis, do not belong to it, but come from a new acid, called persulphuric acid. It seems that persulphuric acid is the first product of the process, and that this persulphuric acid is undoubtedly the agent which is generally formed, and is often characterized as the peroxide of hydrogen. That being the case, therefore, we have to consider cases where we can have a reverse or converse reaction. The action of iodic acid on hydriodic acid is a well-known case. There is undoubtedly a considerable dissipation of energy in the genesis of iodic acid, because it is not endothermic, like chloric acid. The moment the hydriodic acid is mixed with the iodic acid, free iodine and water result. The original constituents appear again without the complication of secondary reactions. It is reactions of that kind that we require. It is to the question of discovering reactions of that kind, without dissipation of energy, that we shall in the future look for the further advance of secondary batteries.

With reference to what has been stated regarding the economical working of the incandescent lamp, it is quite clear that such favorable results can only come from working with an incandescent filament at a very high temperature. There is no reason why the incandescent filament should not yield the same efficiency as the arc. Some years ago I made a series of experiments as to the increase of the amount of luminous intensity with the temperature. Since that time, experiments have been made by Violle and other experimenters. All the results seem to prove that as an average and fair way of representing the facts, sufficient in the mean time for practical purposes; that, above a temperature of 500° C., the mean rate of increase of luminous intensity is as a sixth of the power of the temperature.

This law enables us to calculate the temperature of the incandescent filament. There can be no doubt of the explanation of the advantage of working at higher temperatures. The greater the temperature of the filament, the higher is the mean refrangibility of the emitted light. If blue light is considered, instead of the increase being as the sixth power of the temperature, it moves up to the seventh. In case of the violet rays, the rate of increase would move up to the eighth power of the temperature, and consequently the percentage of rays of high refrangibility is greater at higher temperatures. I still think that there are a great many points in connection with the chemical constitution of the secondary battery which require further investigation.

Mr. KEITH. — I would like to ask Professor Dewar whether he has investigated, either theoretically or practically, the decomposition and re-composition of the sub-salts of lead, such as I considered some time ago, and were the subject of discussion. I think he was not present at the time when I stated my own experiments in that line.

Mr. DEWAR. — No, I regret to say that I have not.

Mr. KEITH. — Taking the solutions known as Goulard's solutions, or sub-salts of lead, which are all very soluble, the peroxide is readily formed and dissolved and re-dissolved in that solution, as my own experiments have shown: so far, I have carried them into practical effect only in laboratory experiments. But I have found that all the electricity is returned as electricity; but, of course, all the energy is not returned.

Mr. DEWAR. — As I understand it, the eventual action is admitted to be, that the peroxide of lead is really produced from the sulphate. All I can say is, that if you take and compress a block of sulphate of lead on a platinum plate, and if it is electrolyzed for hours, you will get a small deposit of peroxide of lead.

Mr. KEITH. — I think the gentleman misunderstood my question. I want to state here, that, from solutions of sub-acetate of lead, there is by electrolytic action deposited upon one pole the peroxide of lead, and metallic lead is deposited on the other pole. The reversal of the current reverses the operation: the peroxide of lead enters the solution, and lead is dissolved. There is a difference of potentials, say, of 1.70 volts.

Prof. GEORGE F. BARKER. — I should like to point out some of the defects in storage-batteries. I made an experiment three years ago with secondary batteries, and I called attention to these experiments in the meeting of the American association at Montreal. I believe that the same thing had been found by Gladstone and Tribe; but I think that it did not excel, although they said in their paper they had seen it referred to. The cells to which I referred were not Faure cells: they were cells of the Planté type, of a peculiar construction. The lead plates were of a peculiar form, but they were entirely separated from each other. They were separated, also, by pieces of wood to prevent the buckling. Now, with regard to whether it was the impurities of the lead or not, I am not inclined to agree with Mr. Keith on that point. The lead, in the first place, was clean. I have no doubt that the claim was a good one, and that it was as absolutely pure as lead could be obtained. Beyond that, they were so placed, that, if the lead was not pure lead, any local action that would take place in the cell on account of the impurities of the material would not affect the general electromotive force of the cell: it would cause a waste of the material, but no other effect, and would not affect the resistance of the battery of this cell, nor its electromotive force.

I attribute this action to the formation of some non-conducting film over the surface of the plates, both the peroxidized plate and the metallic lead plate. There is no doubt about it, both that the metallic lead, in this particular form in which we find it in the secondary battery, is attacked by sulphuric acid, with the formation of sulphate of lead; and that there is a chemical action and reduction of the lead

in the cell, which is also attacked by the sulphuric acid, with the formation of sulphate of lead. We all know that sulphate of lead is a pretty fair insulator. I think the action pointed out by Professor Trowbridge in these cells, and the fact that there was a little sulphate formed during the operation of the cell; the fact that the cell is restored after this prolonged charging, in which, of course, there must be a great loss of energy; and the fact that they are restored to their original condition, — would induce me to believe that it is nothing due to the impurity in the lead, but rather is owing to the non-conducting film, which discolors the plate. Besides that, with regard to the short-circuiting, there is no short-circuiting in the cell. I am quite satisfied from attendant circumstances and observations, and from experiments that were made, that they saw no short-circuiting in the cells.

Before I leave this subject, I should like to say a word or two with regard to the hope that Professor Preece indulged in. I am glad that he has had such an encouraging experience with regard to storage-batteries. I am inclined to think he will be disappointed in the hope expressed, of being able to charge the cells on one day of the week, and then use them during the rest of the week. A very simple calculation would convince him, as well as the conference, that such a plan is not practicable with his present plant. Perhaps, if he increases his plant, he may be able to do it: he cannot do it with what he has on hand. If we take the figures as Professor Preece has given them, of a candle from 2½ watts of energy, a 16-candle lamp would require 40 watts, and that gives us an efficiency of about 18.6, — 16-candle lamps per horse-power of candle-energy, which I must say, in the first place, is good lighting. 40 watts, with 30 volts between its terminals, will give us 31.3 ampères as the current to the lamp. Now, if we suppose that Mr. Preece has, in using 10 lamps, for instance, — I do not know how many there are in the plant used; we will say 10 lamps; put the number small, because 10 lamps are enough for ordinary use, — 10 lamps would require 13 ampères to maintain them. 13 ampères for 3 hours would be 39 ampère hours, we will call it, on an average night, and, for seven nights in the week, would be 273 ampère hours. Now, we divide 273 by the efficiency of the storage-batteries, — forty per cent, — and we will get as the total number of ampère hours, during which the battery must be charged, 682½. If we divide that by the number of hours which the charging would occupy, — twelve hours during the day, — that will give us the time used in charging the storage-battery, to produce this result, and give the current to the storage-battery of 56.9 ampères and 42 volts; in other words, 52 ampères to .8 of an ohm. The charging resistance of the battery would certainly be greater than .8 of an ohm. I call the charging resistance of the battery the difference of tension between the terminals of the battery, while the battery is being charged at the time by the current flowing in the circuit. That is what I designate by the term 'the charging resistance.' The charging resistance I am sure, from my own experiments, cannot be less than 2 ohms. Second, The current of his machine would be very materially reduced. Besides that, admitting that he could get this current of merely 57 ampères, which he requires for charging the battery, the question is, How long would his cell stand a current of that magnitude? I am inclined to think that a very few weeks' charging with a current as great as that would very soon use up his cells.

Mr. PREECE. — The assumption of the temperature he starts with there, is wrong; for I am only using ten-candle lamps, and they absorb nine-tenths of an ampère. If you go through with a calculation on paper, you are sure to make a mistake. My calculation shows that you can get two hundred ampère hours out of my battery: if so, I shall have enough to last me a whole week; and the batteries, I am quite sure, after they have been used a little time, will give me that, and a margin to spare. I am quite certain, notwithstanding those figures that I had the pleasure of going over, that I shall be able to report, that, from one day's charging, I have got my light for a week.

I will mention one fact, which I mentioned to you this morning, that my gardener cut off the top of his foot: at that time my battery was charged up Friday morning. I had a dinner-party Friday night; and whenever we have dinner-parties we make all the show we can. On Saturday I had no dinner-party, and I used my lamps as usual. On Sunday I used my lights as usual. On Monday morning my man cut off his toe. I had a dinner-party on Monday night, and I did not know of the accident at all. I got down just in time to dress for dinner. Without saying a word to anybody, I trusted to my battery; and I found my battery held on for the whole of that night. I had, without any further attention to the battery, sufficient light for two dinner-parties and four days. And I think if we did that in an emergency, with a little gentle care that could be given, I shall not be far wrong in saying that I shall have enough for a week's use.